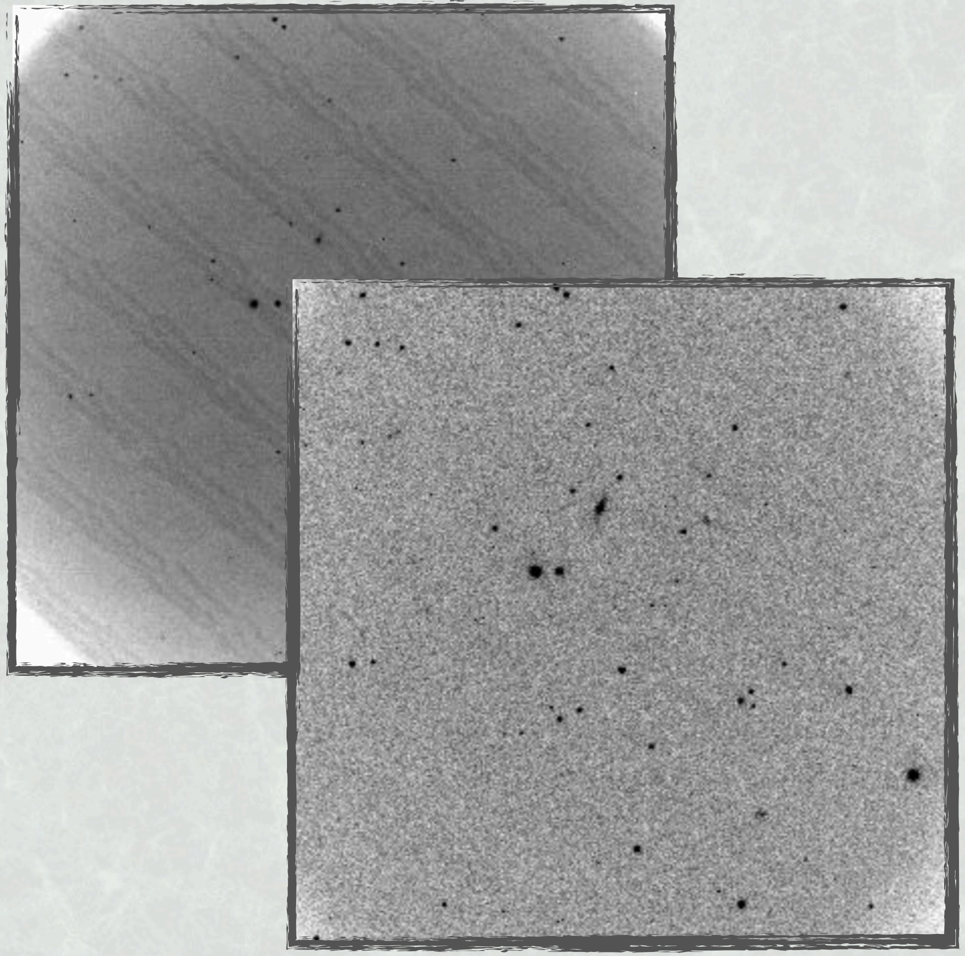
Observational Astronomy & Data Reduction

Lecture 6:
Photometry — the basics



Karín Menéndez-Delmestre
Observatório do Valongo

Syllabus

I. Basics Concepts in Observational Astronomy:

- Telescopes
- coordinate systems
- Image Quality

II. Signal and Sources of Noise

- Detectors
- Poisson statistics
- shot noise
- sky
- Read noise
- dark current

III. Observing Strategies
& Planning your observing night

IV. Basics of Data Reduction

- Bias, Flats, Darks
- What, Why, When, How long and How many

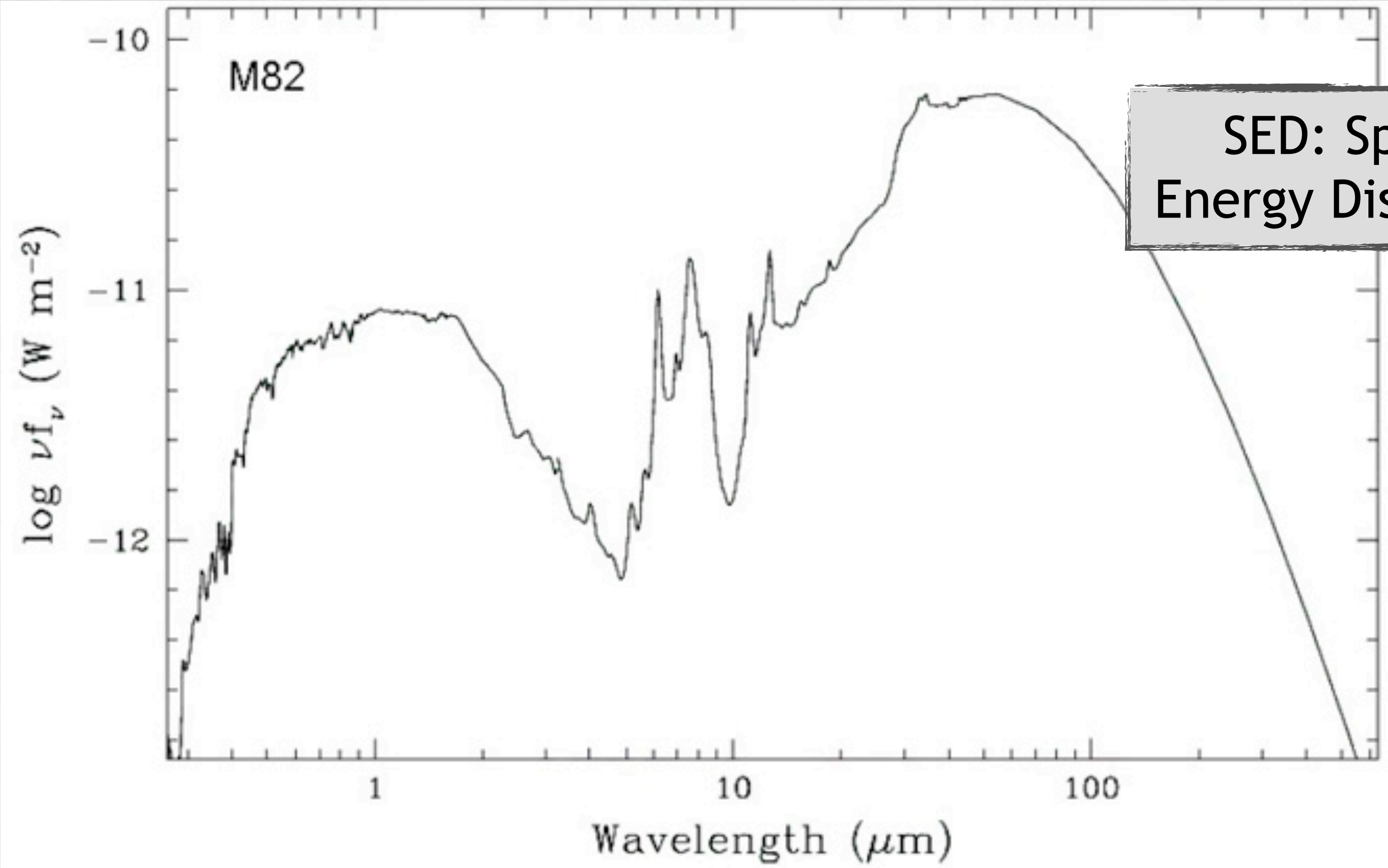
V. Data Reduction

- Simple arithmetics!
- Bringing in the computer tools*
- Using basic IRAF routines or Python

VI. Basic Aperture Photometry

Photometry

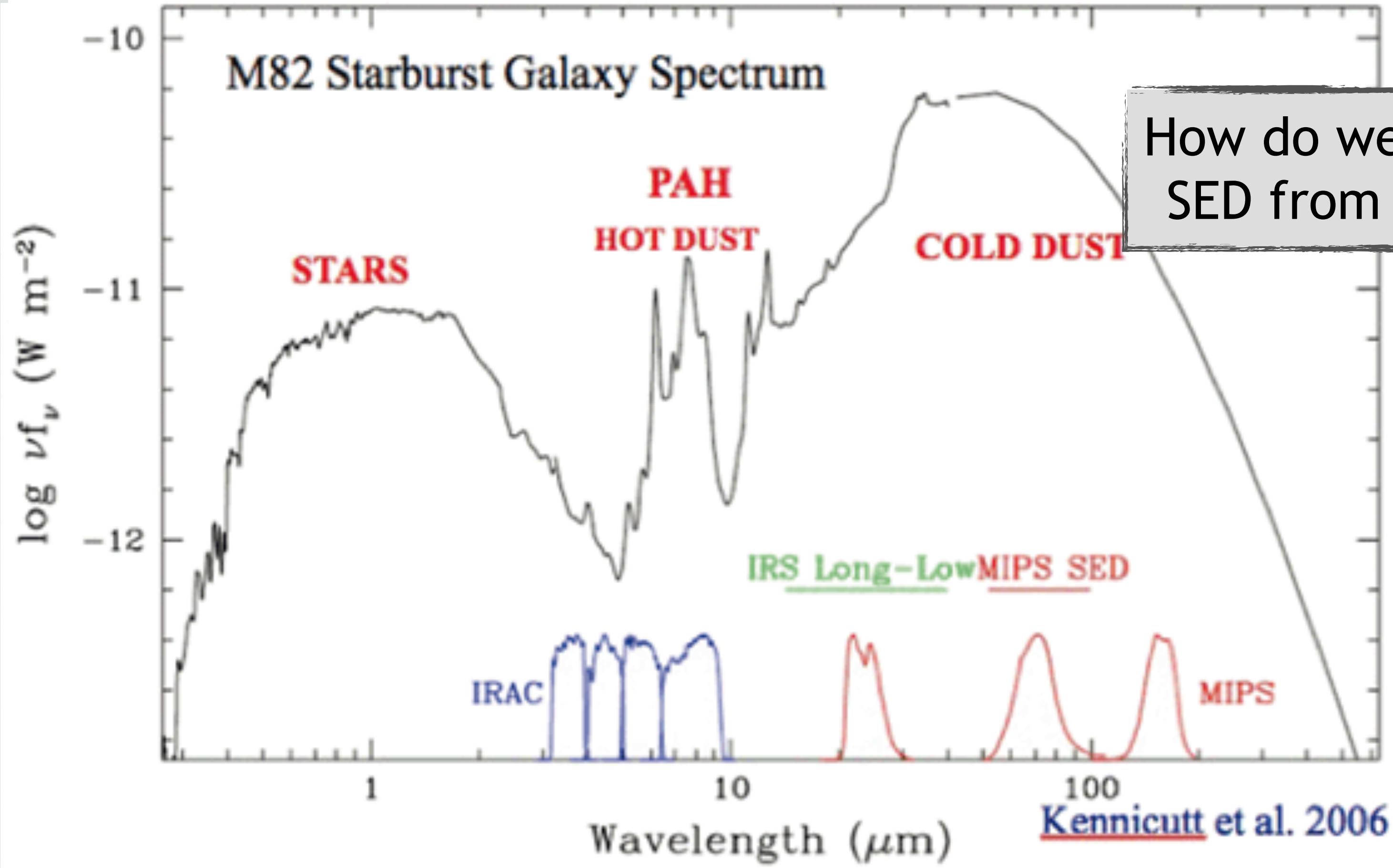
- Objetive:
  - → measure light from a point source (mag)
  - → measure surface brightness from an extended source (mag/arcsec²)



SED: Spectral Energy Distribution

Photometry

- Objetive:
  - → measure light from a point source (mag)
  - → measure surface brightness from an extended source (mag/arcsec^2)



How do we build an SED from scratch?

Photometry

- Objetive:
  - → measure light from a point source (mag)
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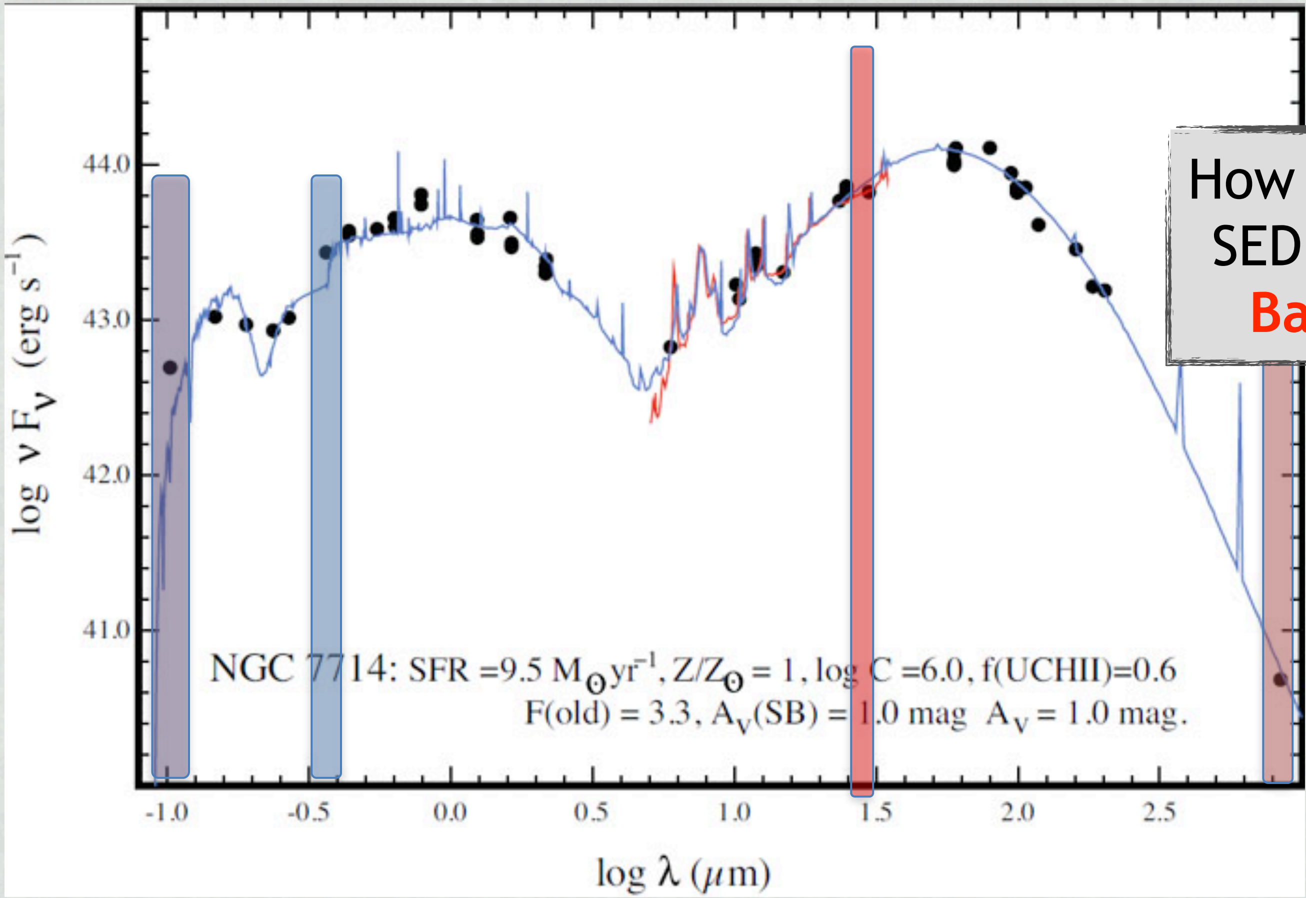
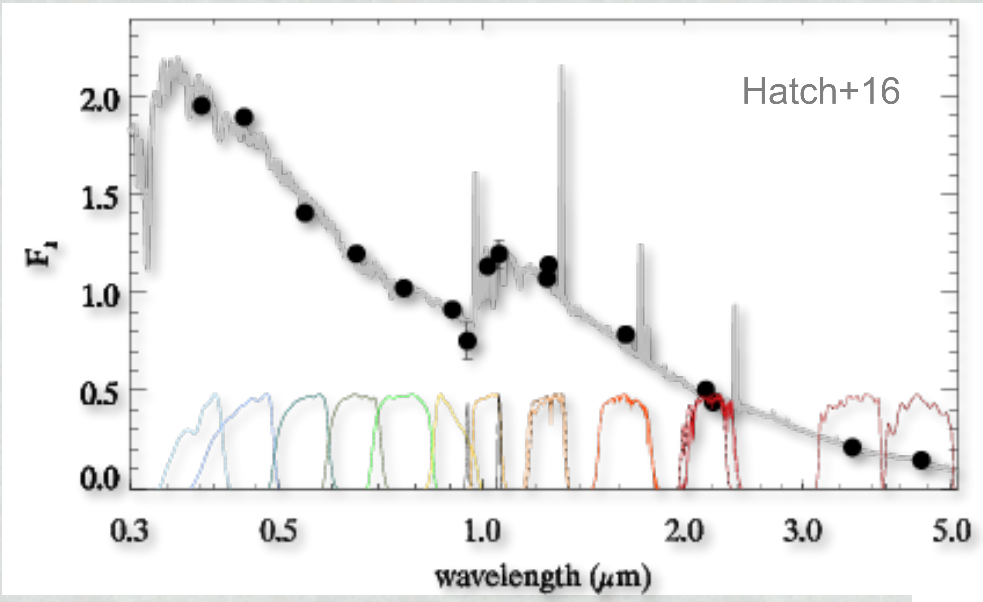


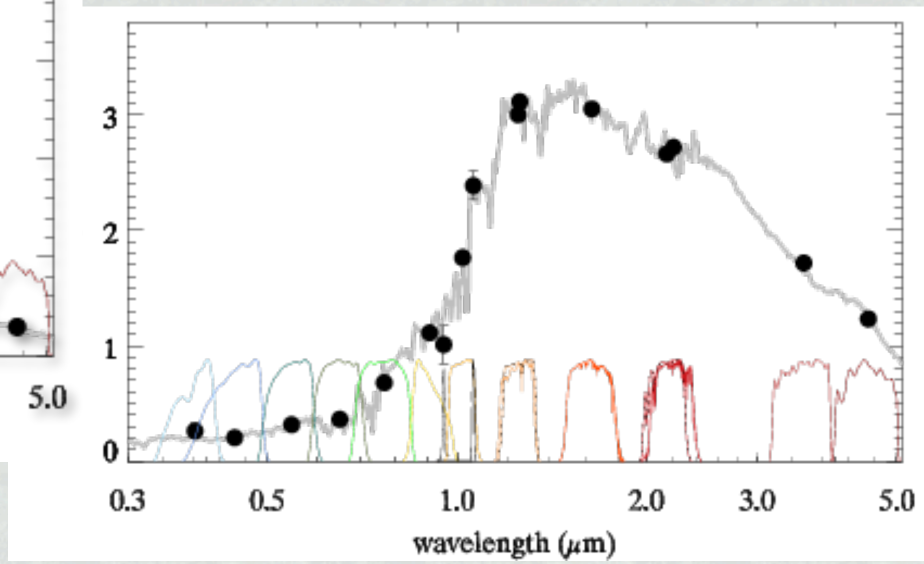
How do we build an SED from scratch?
Band by band!

http://ned.ipac.caltech.edu/level5/March10/Walcher/Walcher2.html

Photometry

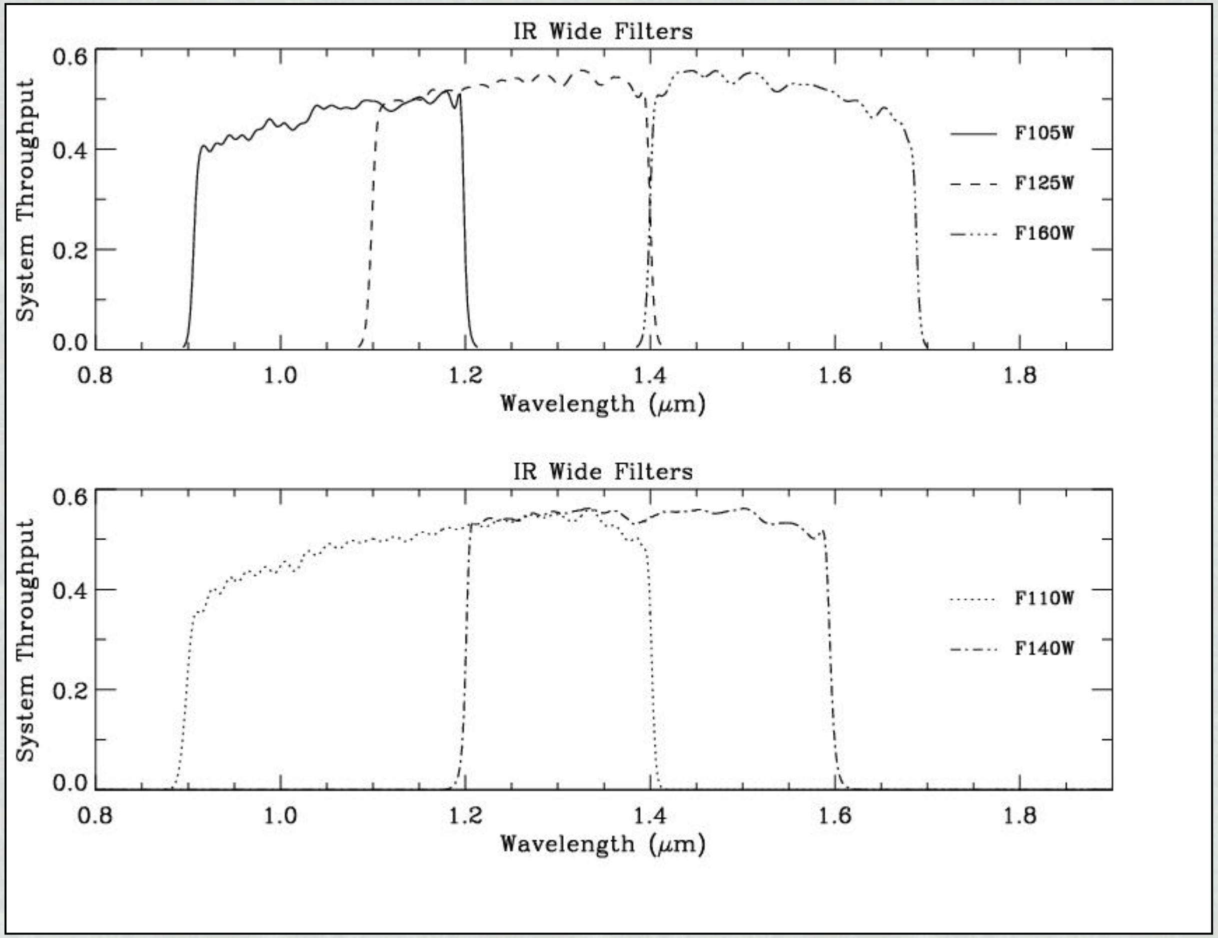
- Objetive:
  - → measure light from a point source
  - → measure surface brightness from an extended source
- Can think of it as extremely low-resolution spectroscopy:
  - Wide-field photometry allows us to build the SED of hundreds of sources at the same time





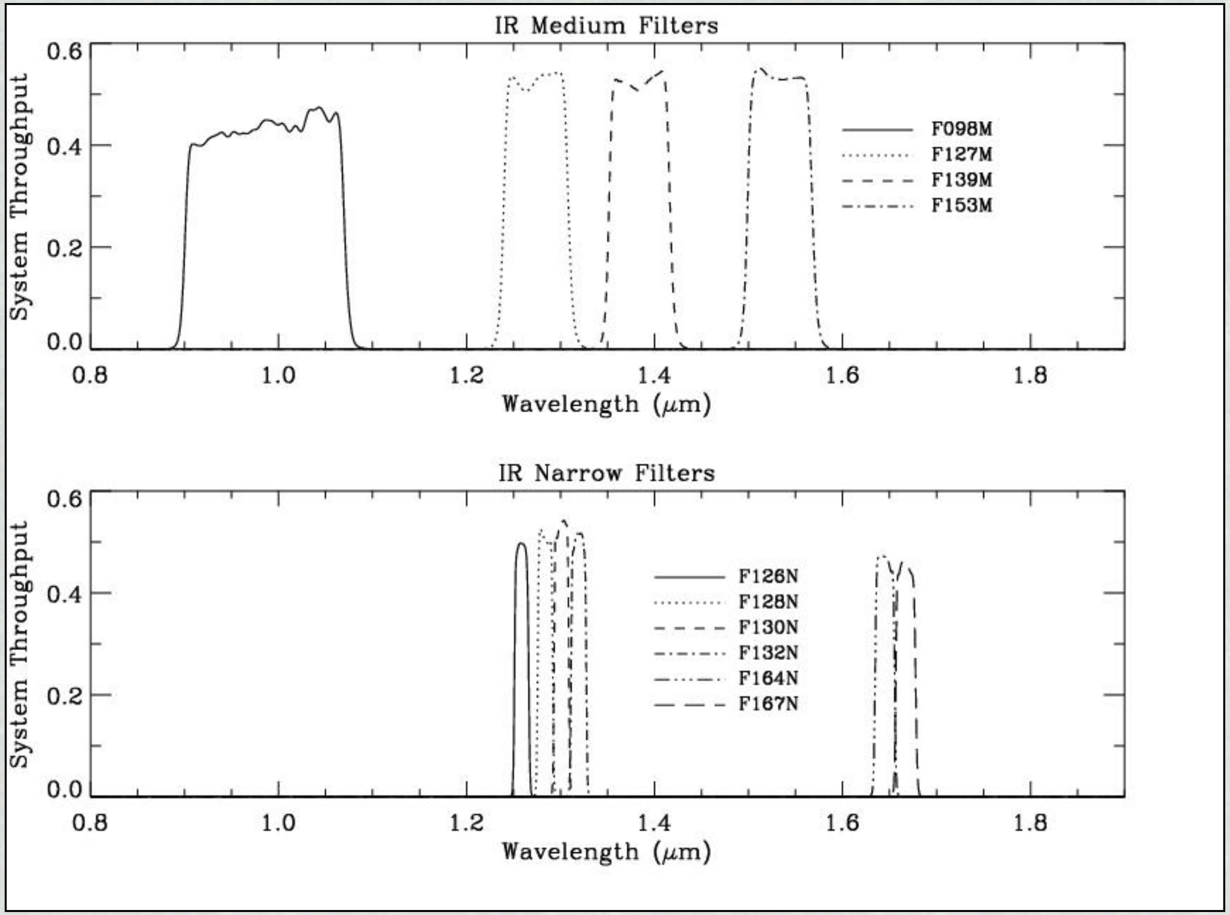
Filters: broad, medium, narrow

– broad-band: 100 nm



Filters: broad, medium, narrow

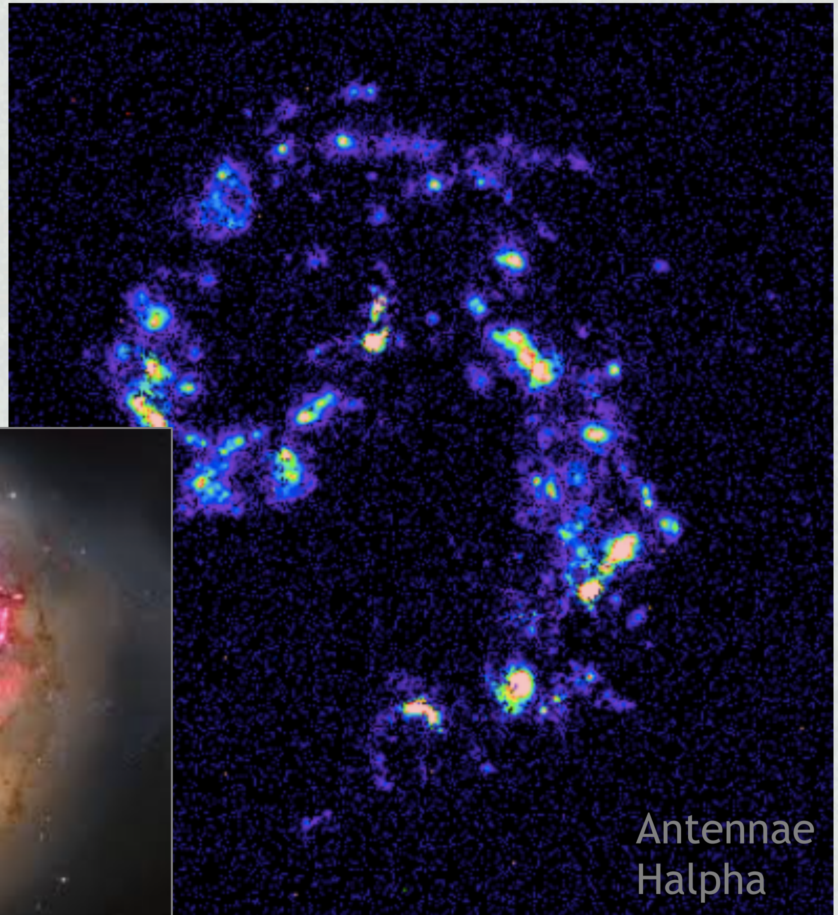
- broad-band: 100 nm
- intermediate:
  - 10 – 50 nm
- narrow-band:
  - 0.05 – 10 nm



Filters: broad, medium, narrow

- broad-band: 100 nm
- intermediate:
  - 10 – 50 nm
- narrow-band:
  - 0.05 – 10 nm

→ narrow-band filters are typically designed to capture photons from a given emission line



http://www.ctio.noao.edu/new/Telescopes/SOAR/Instruments/SAM/ao_fl_news_archive.html

Filters: broad, medium, narrow

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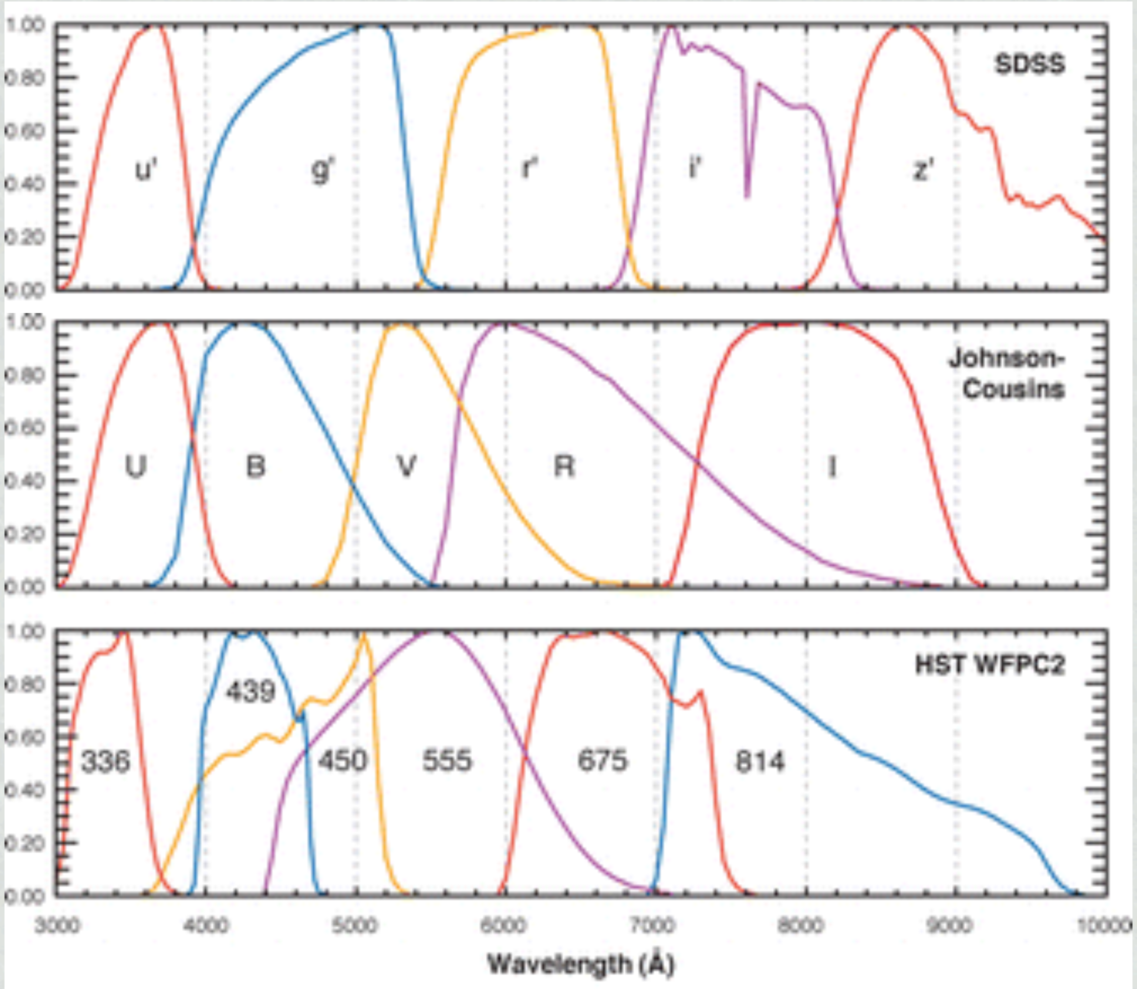

<u>Many filter systems:</u>

- SDSS: u'g'r'i'z'
- Johnson: UBVRI
- Instrument-specific (e.g., HST)

Filters: many filter systems!

ADPS The Asiago Database on Photometric Systems | home | ReadMe | Paper 1 | systems list | bibliography | GCPD

Guide Star Catalogue - Lasker *et al.* - 1990	138	133
UIT - 1990	139	157
JHKL'M ESO - Bouchet *et al.* - 1991	140	
POSS II - Reid *et al.* - 1991	141	134
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MANIAC - Böker *et al.* - 1997	158	
Damineli *et al.* - 1997	159	142
TNG - Marchetti *et al.* - 1997	160	144
$UBV(RI)_{MW}$ - Sandage - 1997	161	
UWTAT - Strassmeier *et al.* - 1997	162	145
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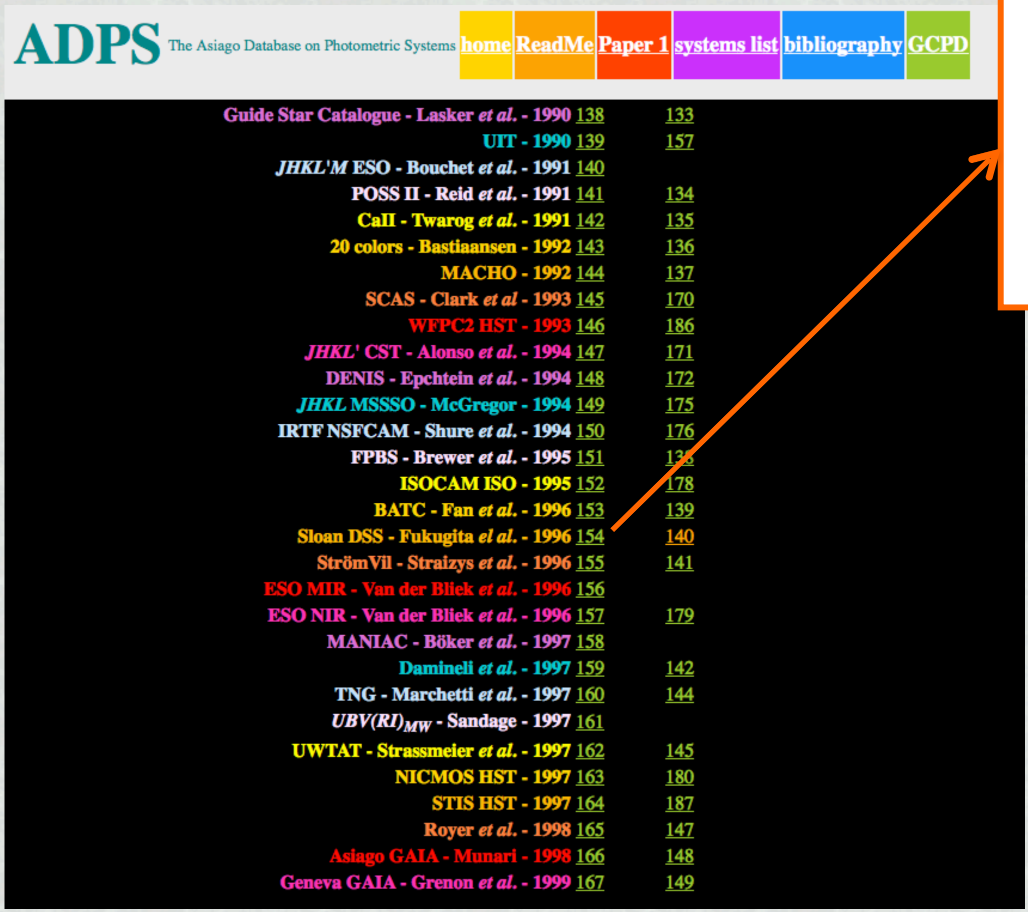
STIS HST - 1997	164	187
Royer *et al.* - 1998	165	147
Asiago GAIA - Munari - 1998	166	148
Geneva GAIA - Grenon *et al.* - 1999	167	149

- Asiago database of photometric systems
  - Information on > 200 photometric systems
  - web based: http://ulisse.pd.astro.it/Astro/ADPS/Systems/index.html

Filters: many fi



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Sloan DSS - Fukugita et al. - 1996

band	λ_{eff} (Å)	FWHM (Å)
u'	3557	599
g'	4825	1379
r'	6261	1382
i'	7672	1535
z'	9097	1370

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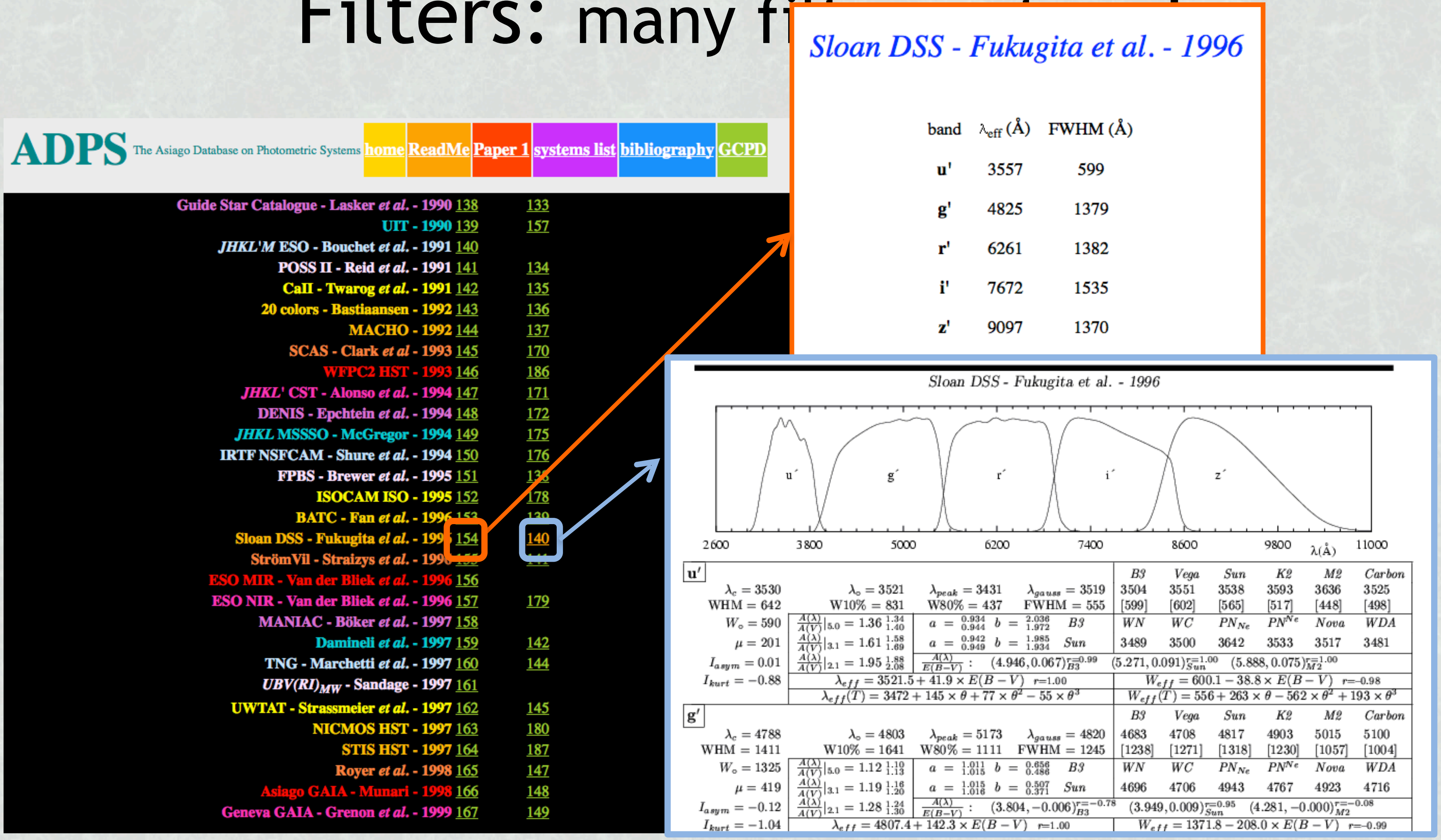
Filters: many fi



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  - Information on > 200 photometric systems
  - web based: http://ulisse.pd.astro.it/Astro/ADPS/Systems/index.html

Point-source Photometry – hands on!

- Objetive:

→ measure light from a point source (mag)

- A few simple steps:

Based on our reduced images, we need to:

(1) Determine the source's centroid

(2) Define an "aperture"

→ Defines the region where we calculate the flux associated to the source

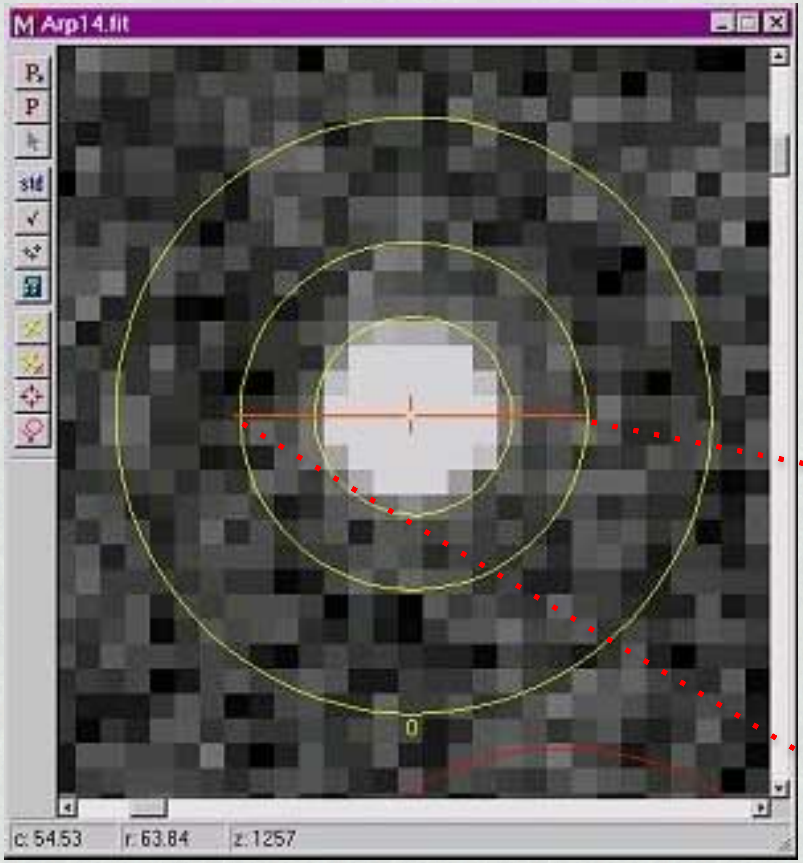
→ Use same aperture for standard star

(3) Measure sky background (<sky/pixel>)

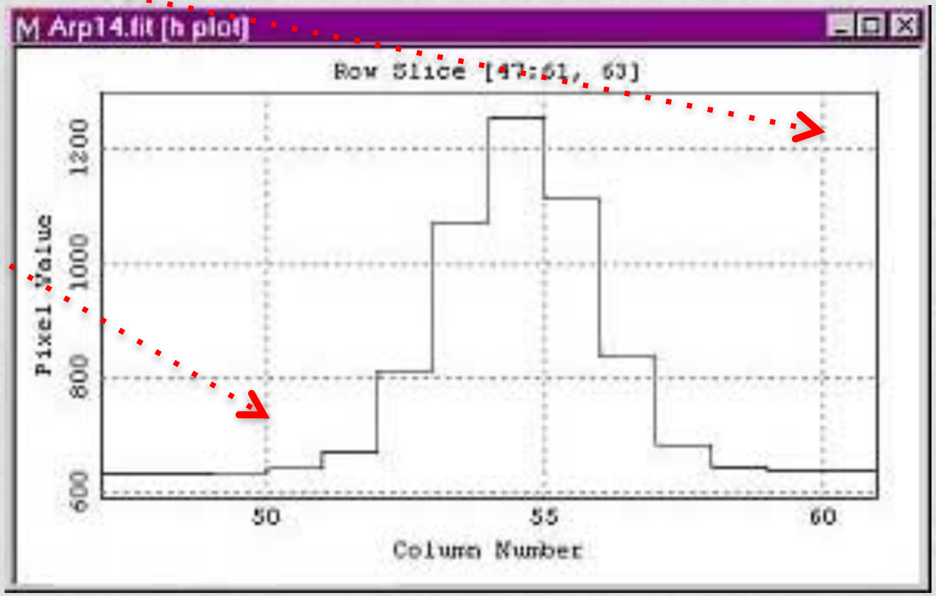
http://spiff.rit.edu/richmond/asras/comet_phot/comet_phot.html

Point-source Photometry – (1) Define centroid

- Brightness profile – relatively symmetrical cases are simple



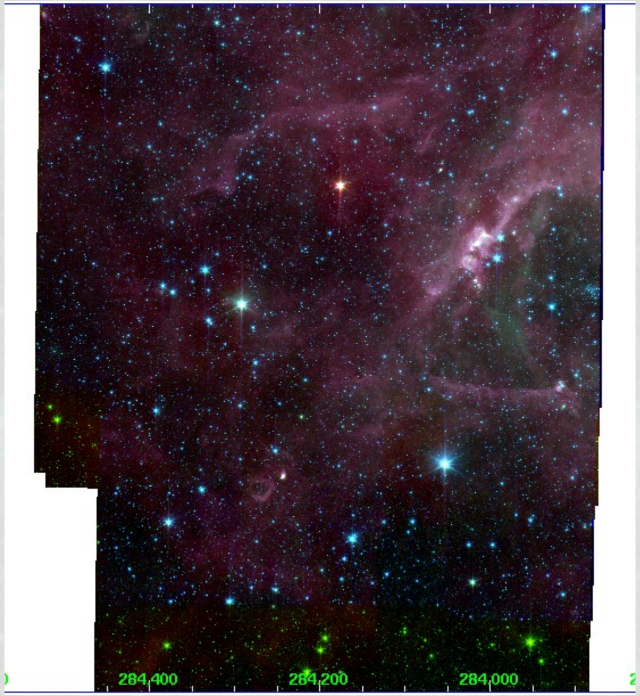
Gaussian is a reasonable fit
in many cases



http://www.opticstar.com/Run/Astronomy/Astro-Editorial-Articles-Mirametrics.asp?p=0_10_19_1_4_7

Point-source Photometry — (1) Define centroid

- Brightness profile – relatively symmetrical cases are simple
  - But there are more complex cases, of course!



http://wise2.ipac.caltech.edu/staff/jarrett/wise/figures/GLM_28420-0098.jpg

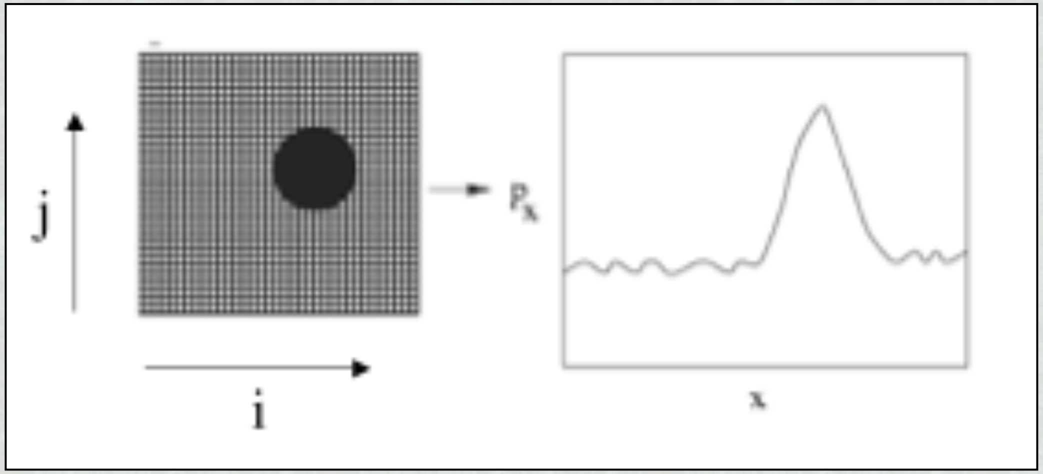
Point-source Photometry — (1) Define centroid

- Consider a brightness distribution

  Sum along columns:

$$\rho_{x_i} = \sum_j I_{ij}$$

  I_{ij} = counts on pixel (i, j)



- Weighted sum

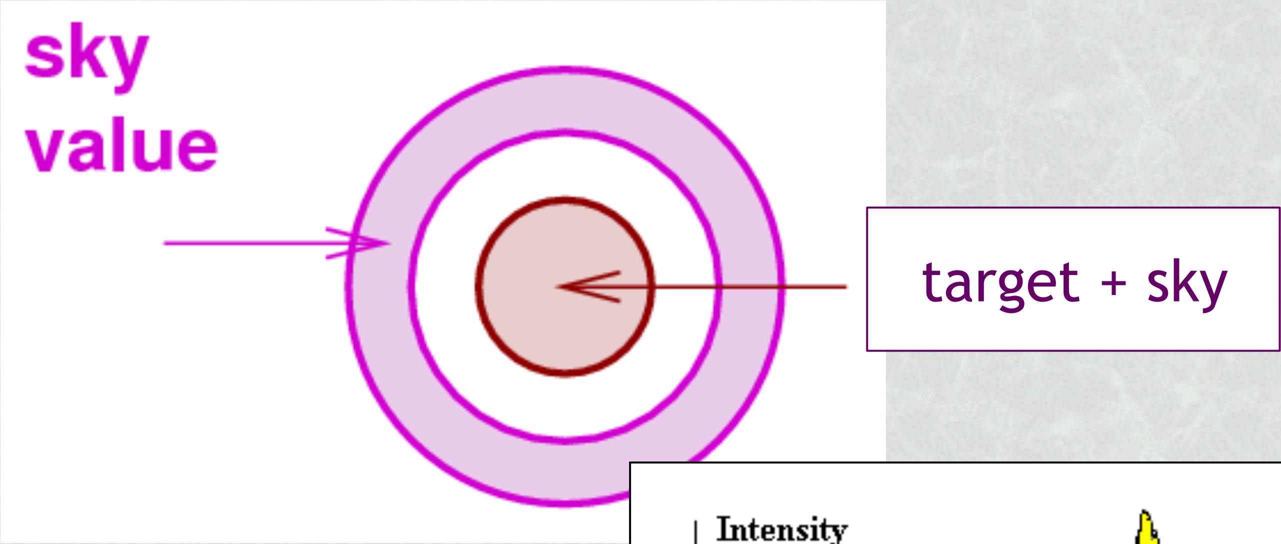
  (intensity-weighted centroid)

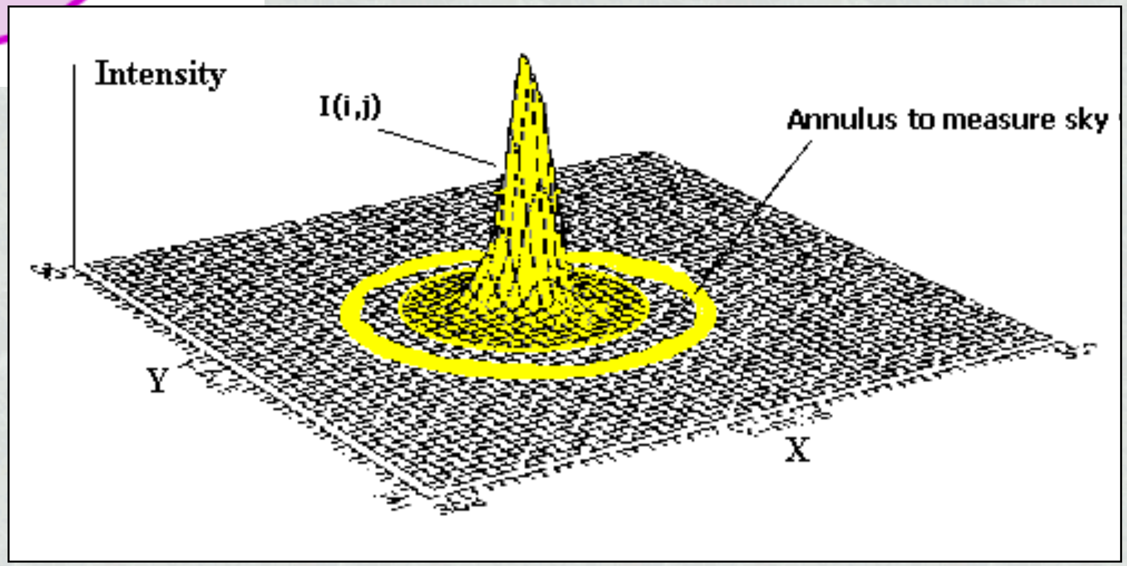
weight

$$x_{center} = \frac{\sum_i \rho_{x_i} x_i}{\sum_i \rho_{x_i}}$$

Point-source Photometry — (2) Sky Background

- Objective: get the median value of the sky background (per pixel)





http://spiff.rit.edu/richmond/asras/comet_phot/comet_phot.html

http://infohost.nmt.edu/~bryan/research/indstudy/phot1/photlab.html

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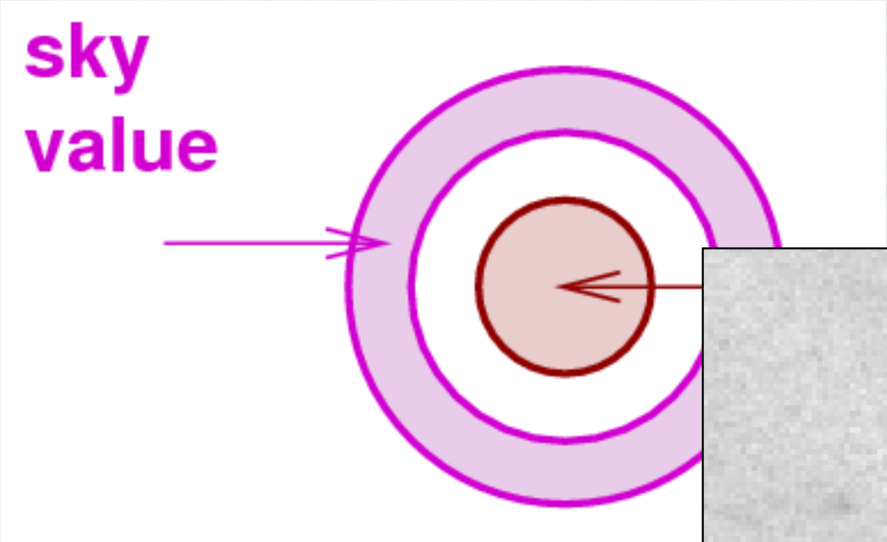
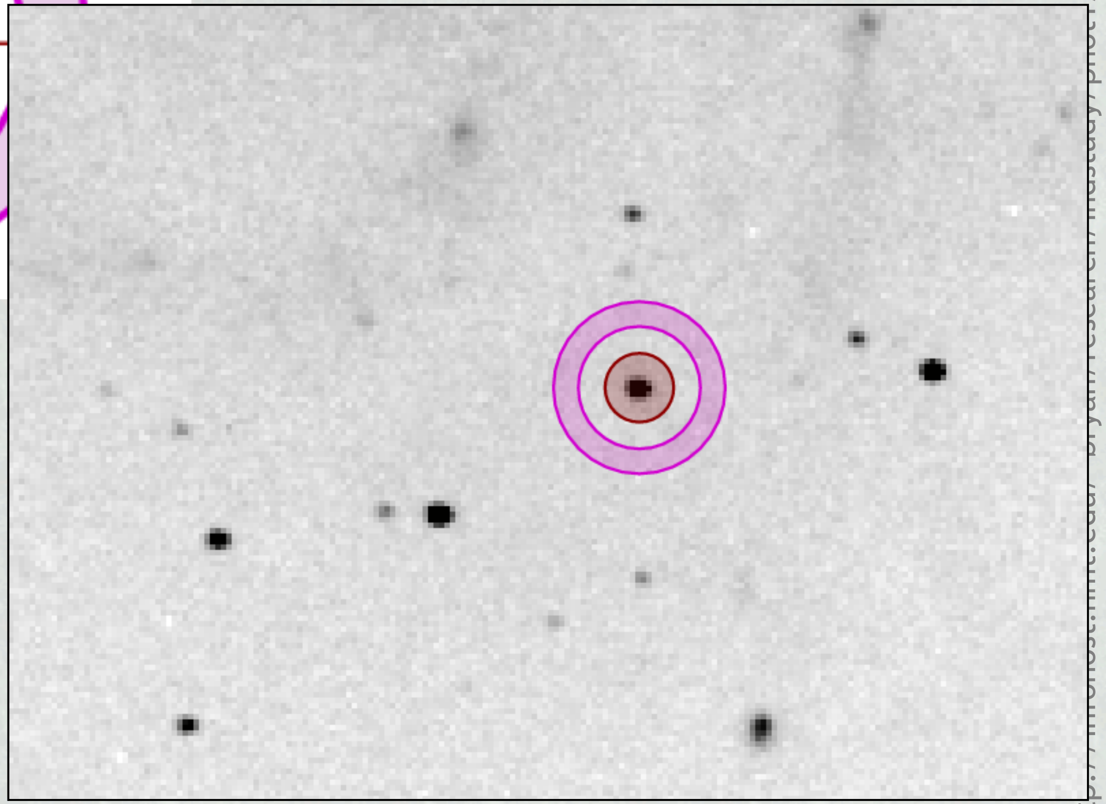


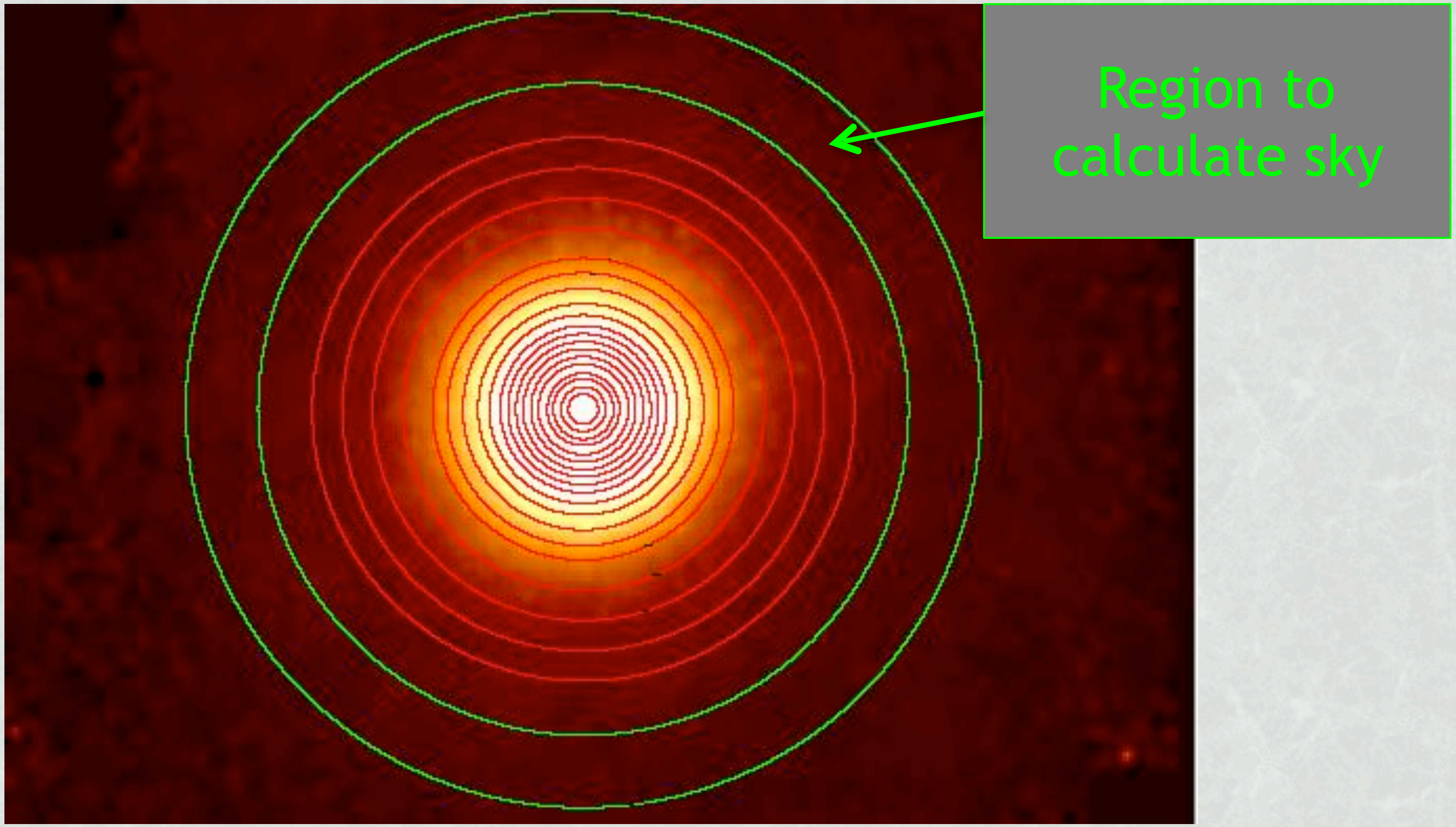


http://spiff.rit.edu/richmond/asras/comet_phot/comet_phot.html

http://…/photlab.html

Point-source Photometry – (3) Define aperture

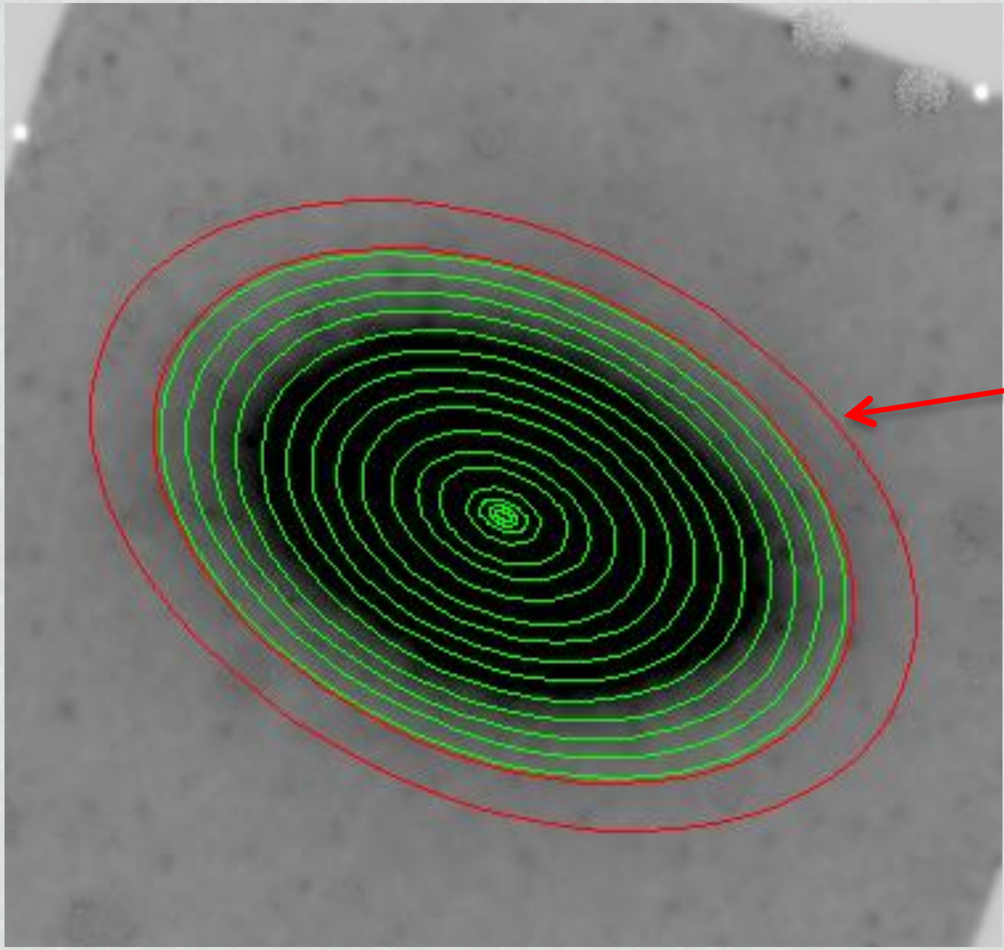
- Circular Aperture



http://wise2.ipac.caltech.edu/staff/jarrett/wise/ext_src.html

Point-source Photometry – (3) Define aperture

- Circular Aperture
- Elliptical Aperture



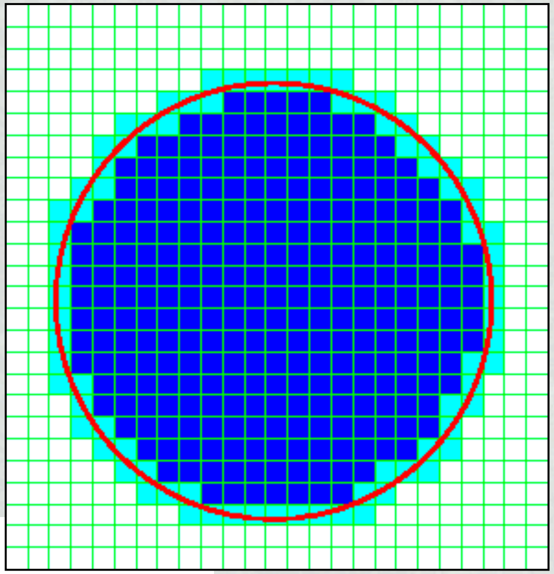
Region to calculate sky

NGC0584 (SINGS)
T. Jarret (2006)

http://www.ast.uct.ac.za/~jarrett/irac/calibration/ngc0584.html

Point-source Photometry

- All ingredients in hand!



$$I = \sum_{ij} I_{ij} - n_{pix} \times \text{sky/pixel}$$

Total counts in aperture from source

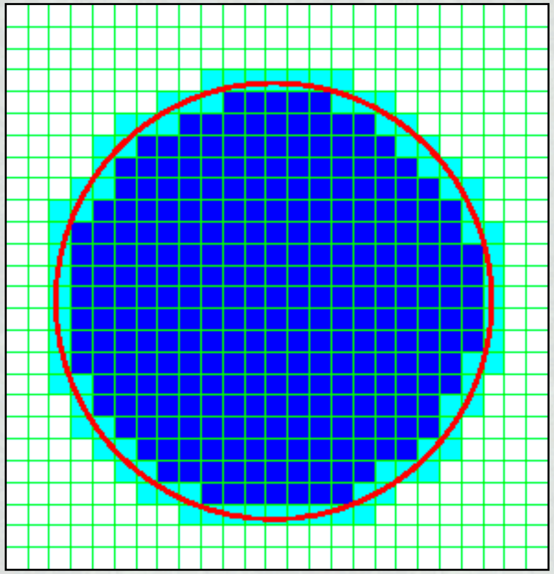
Counts in each pixel in aperture

Number of pixels in aperture

$$m = c_0 - 2.5\log(I)$$

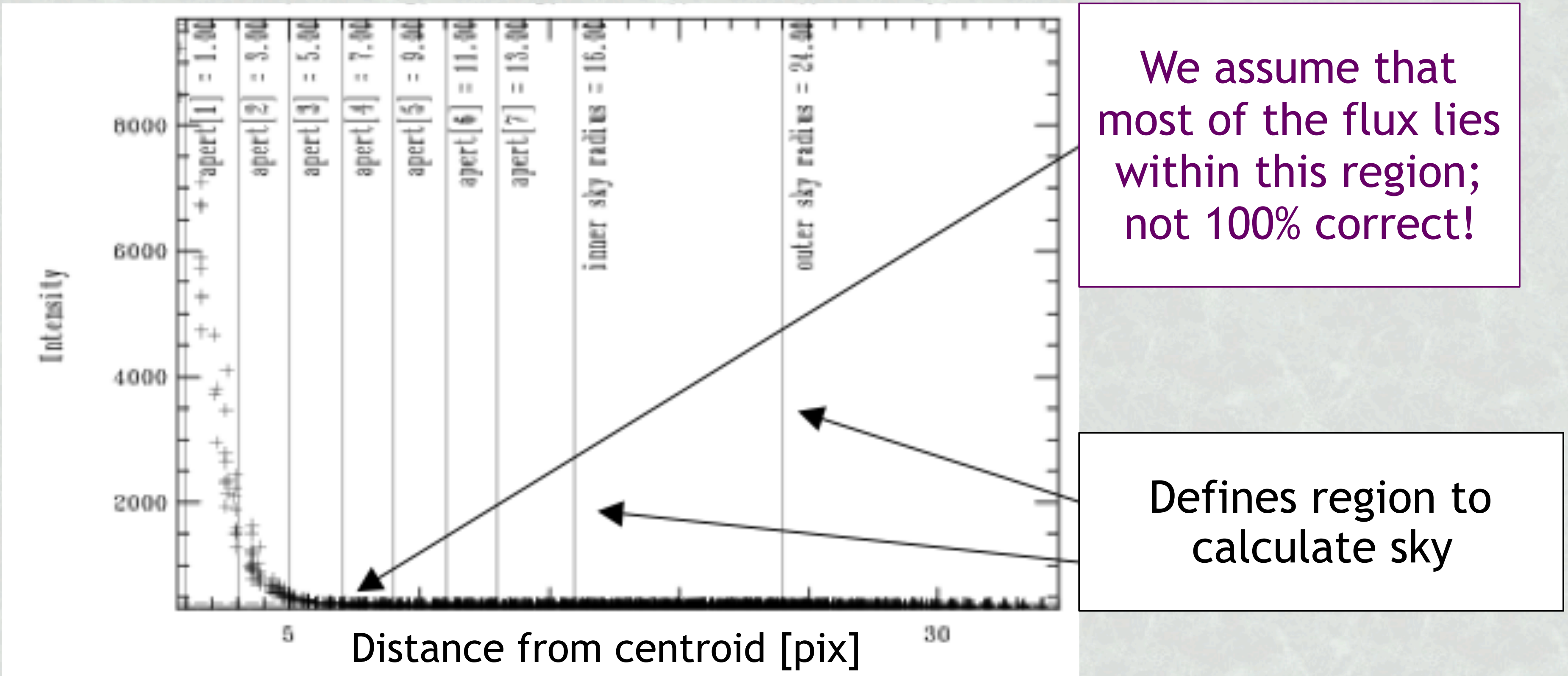
Point-source Photometry

- All ingredients in hand!
- Additional considerations:
  - circular/elliptical aperture… but square pixels!



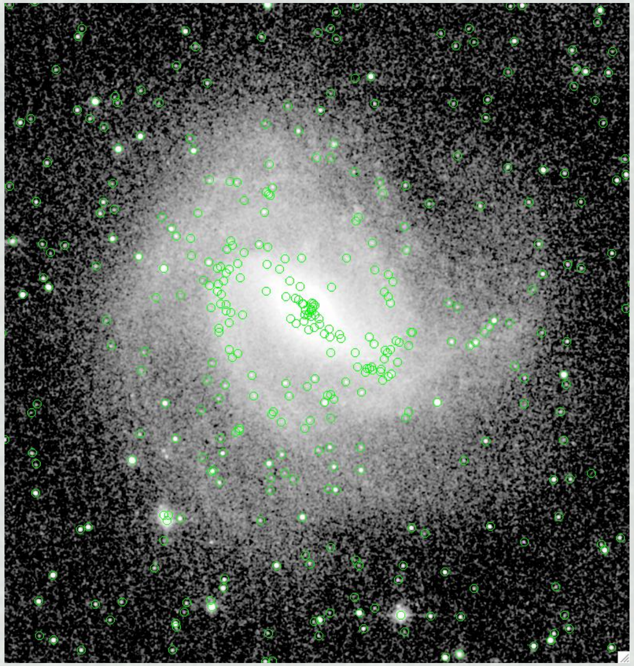
Point-source Photometry

- All ingredients in hand!
- Additional considerations:
  - circular/elliptical aperture… but square pixels!
  - Flux extends beyond aperture
    - Aperture loss correction (i.e., add a term to correct for this)



Point-source Photometry

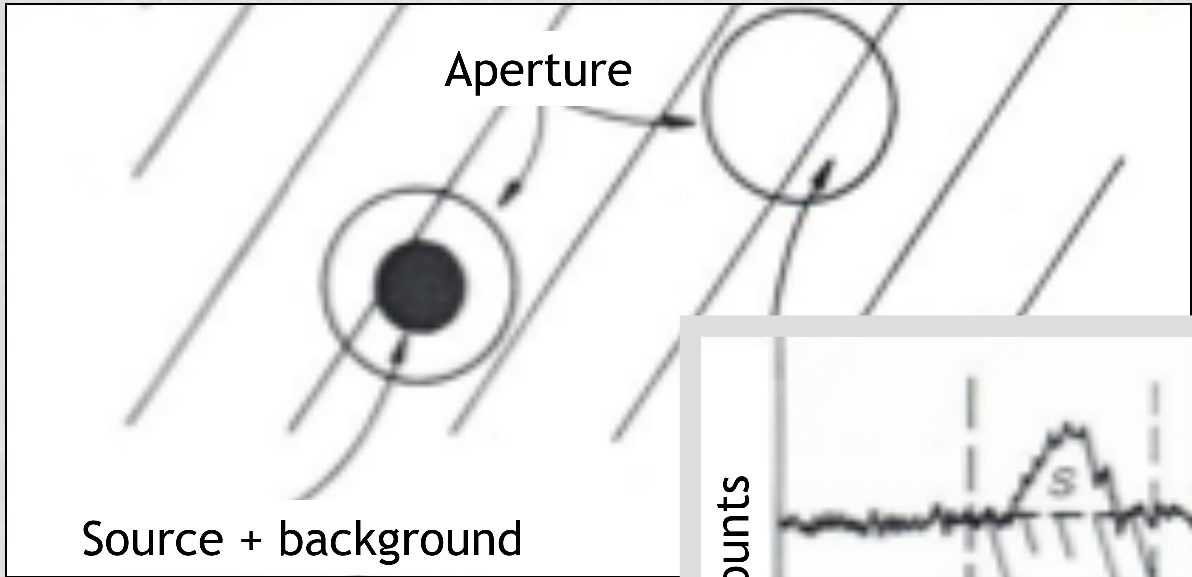
- All ingredients in hand!
- Additional considerations:
  - circular/elliptical aperture… but square pixels!
  - Flux extends beyond aperture
    - Aperture loss correction (i.e., add a term to correct for this)
  - Point sources may be superposed on extended regions of emission
    - Extra care in defining the sky background!

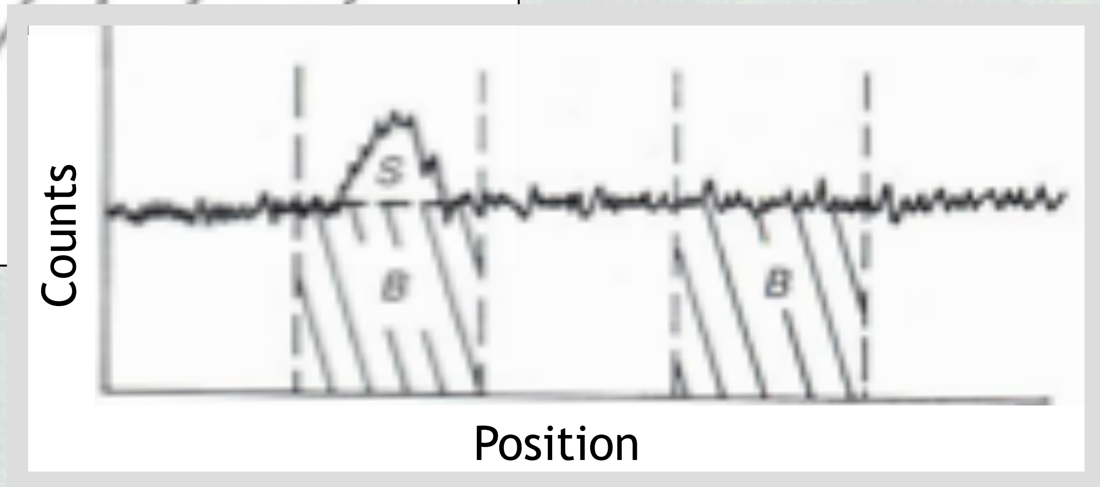


http://wise2.ipac.caltech.edu/staff/jarrett/wise/ext_src.html

Point-source Photometry

- Objetive → measure light from a point source (in mag units)





- Need to go from "counts" to calibrated flux units
  - Need a relation that allows us to convert from an instrumental signal (in count units) to a flux (ergs/s/cm²/Hz)

S_c [counts]

→ f_c [erg/s/cm²/Hz]

→ m_c [mag]

Point-source Photometry — flux calibration

- Need to define the Zero Point (ZP):

$$ZP = m_c + 2.5\log(S_c/t)$$

  - where:
    - S_c is the number of counts from calibration star generated by an image with an exposure time t
    - m_c is the (know) magnitude of the star (from catalogs: e.g., SDSS, 2MASS)
- We are defining the constant (ZP) that, added the instrumental flux, $-2.5\log(S_c/t)$, will allow us to recuperate the known magnitude of our calibrator.
- With this constant, ZP, we can obtain the magnitude of any other point source with measured signal *S*, using the following formula:

$$\mathbf{m_* = -2.5\log(S_*/t) + ZP}$$

Point-source Photometry — get centroid & aperture

- Using ds9:
  - Select the target of interest by clicking on its location and creating a circular region around it (note: a circular region is the default)
  - Double-click —> Define a reasonable size (e.g., PSF)
    - ~2” —> 11pix
  - Analysis —> Statistics
    - Center: coordinates (pixels)

Point-source Photometry — get source, standard's and sky counts

- Using ds9:
  - Select the target of interest by clicking on its location and creating a circular region around it (note: a circular region is the default)
  - Double-click —> Define a reasonable size (e.g., PSF)
    - ~2" —> 11pix
  - Analysis —> Statistics
    - Center: coordinates (pixels)
    - Sum: total counts within target's aperture (1695106)
    - Sky: use same region, slightly offset from target:
      - Sky counts: 888415
    - Sky-subtracted counts: 806691
    - Standard star #2: 1118808 (LTT 1788)
      - Sky-subtracted counts for standard star: 1118808 - sky (869229) =249579
      - V = 13.16, B-V = +0.47 —> B=13.63*

[* http://www.eso.org/sci/observing/tools/standards/spectra/stanlis.html](http://www.eso.org/sci/observing/tools/standards/spectra/stanlis.html)

Point-source Photometry — get zero point

- To calculate the ZP:

$$ZP = m_c + 2.5\log(S_c/t)$$

  - S_c = 249579
  - t = 10s
  - m_c = B=13.63

  - —> ZP = 13.63 + 2.5*log (249579/10) = 24.62

Point-source Photometry — ta-taaaaa!

- Use the calculated ZP to obtain the magnitude of any source in your image:

    - ZP = 24.62

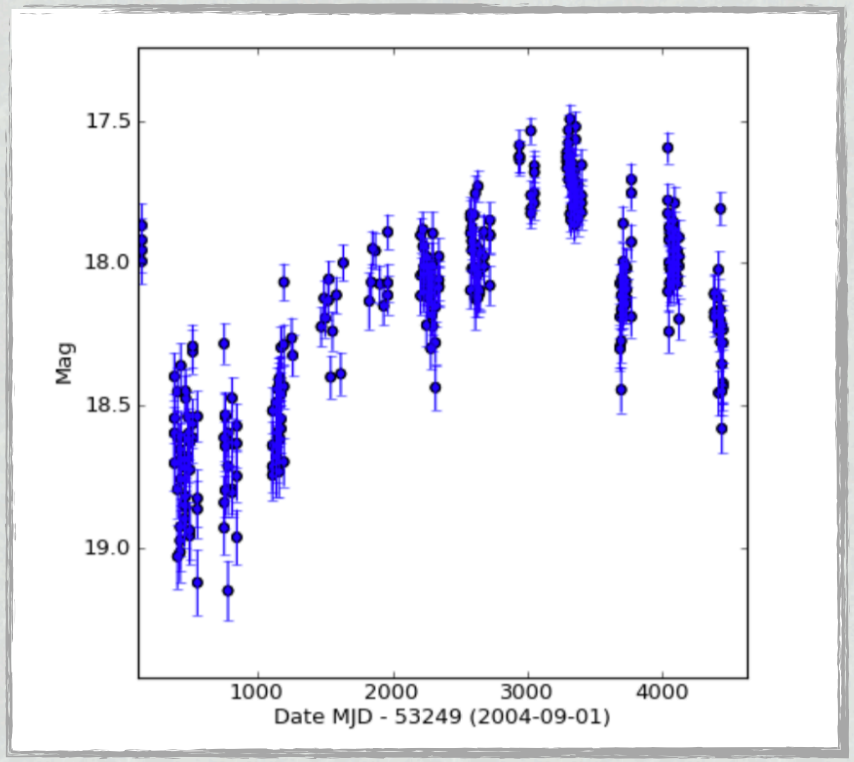
- For our target:

$$m_* = -2.5\log(S_*/t) + ZP$$

—> $m_{AGN\_B} = -2.5*\log(806691/300) + 24.62 = 16.04$ mag

Point Source Photometry –

- Objetive:
  → measure light from a point source (mag)



Lightcurves – AGN variability!

Point Source Photometry –

- Objetive:
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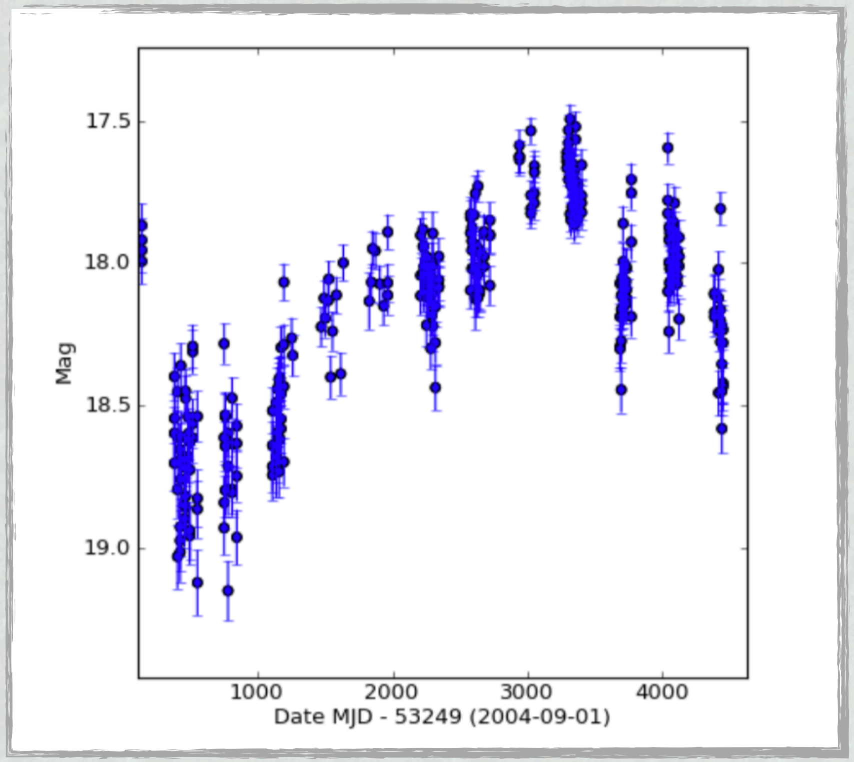

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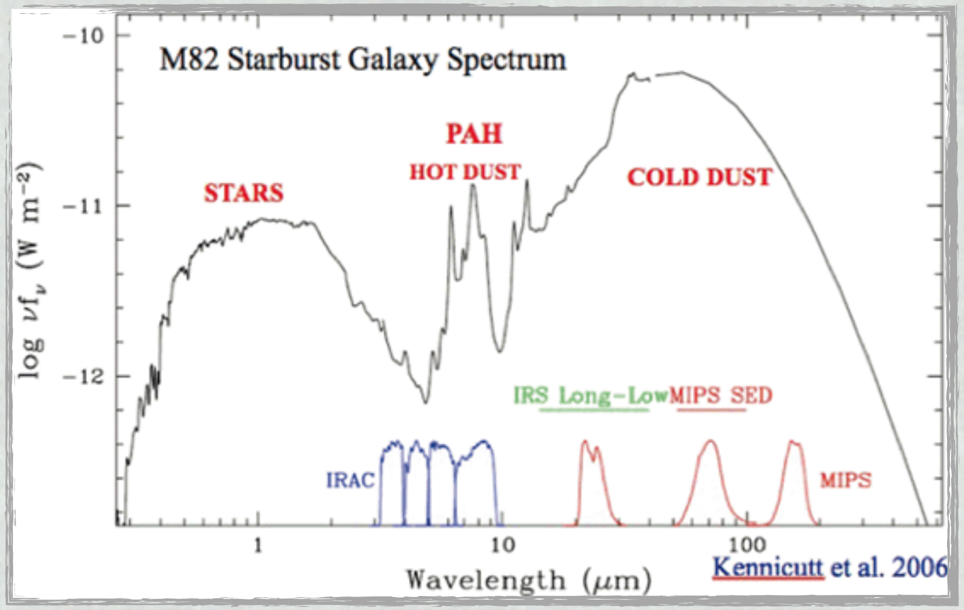


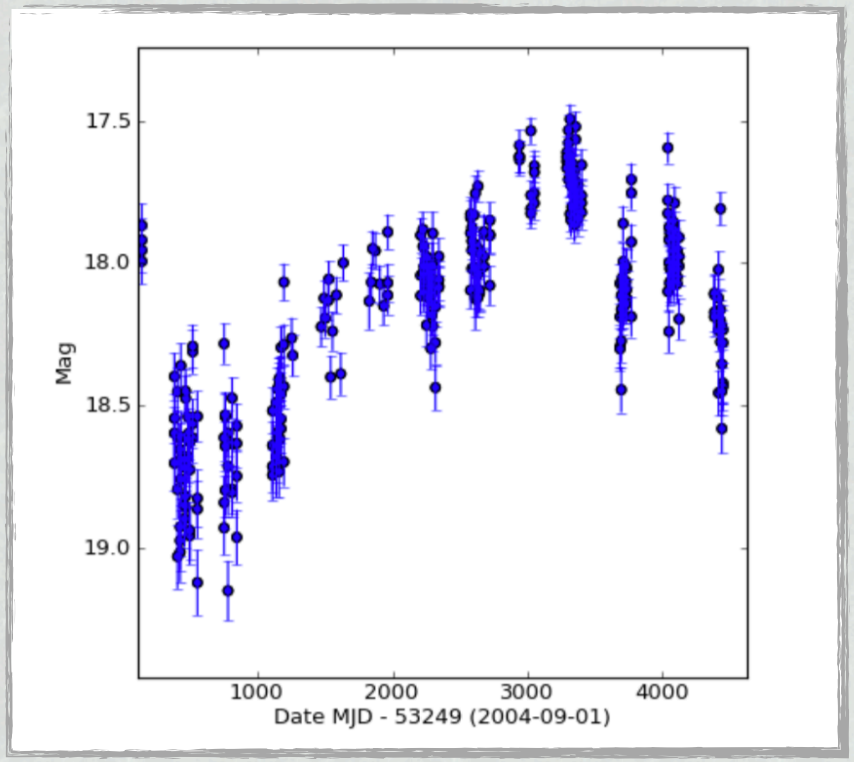
SEDs

Point Source Photometry –

- Objetive:

→ measure light from a point source (mag)

ASTROPHYSICS!!!!



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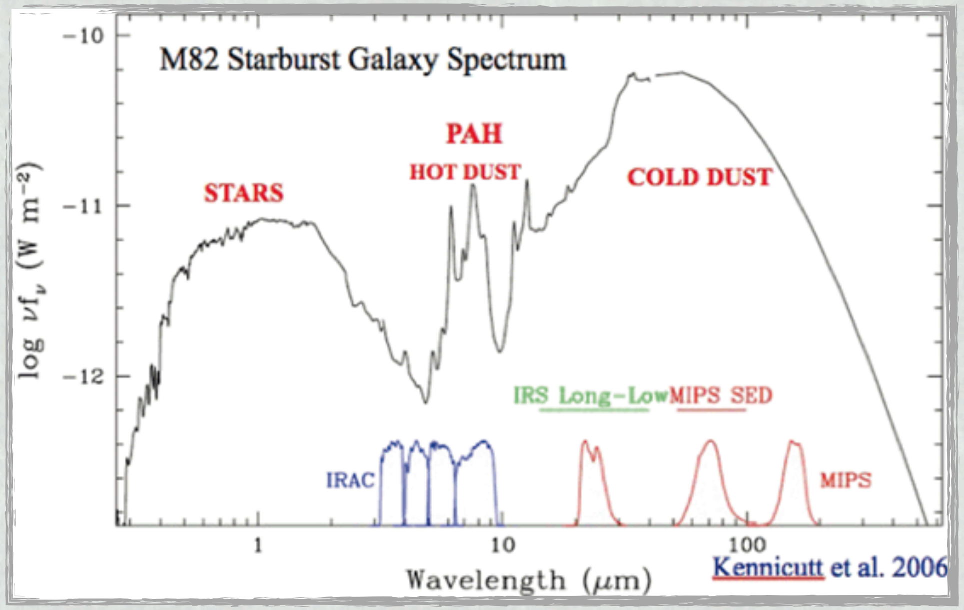

SEDs

Useful references

- Understanding noise, propagating errors and calculating signal-to-noise:
  - *Data Reduction & Error Analysis for the Physical Sciences*, Bevington & Robinson, 3rd Edition, 2003
  - http://hosting.astro.cornell.edu/academics/courses/astro3310/Books/Bevington_opt.pdf
- Data Reduction:
  - *Astronomy Methods* – Bradt, H., Cambridge University Press, 2004
  - *Astrophysical Techniques* – Kitchin, C. R., IOP Publishing, 1998 (3a edição)
  - *Observational Astronomy*, , Birney, D. S., Gonzalez, G., Oesper, D., Cambridge University Press, 2006 (2a edição)
- Other useful online sources:
  - http://spiff.rit.edu/richmond/asras/comet_phot/comet_phot.html
  - IRAF tutorial (a hands-on step-by-step guide to learn some basic routines in IRAF)
    - Follow the *irafintro* guide @ https://www.astro.ufl.edu/~lee/ast325/helpfiles/iraf/